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AIRPLANE DUSTING IN THE CONTROL OF MALARIA MOSQUITOES

W. V. KING, Associate Entomologist
and
G. H. BRADLEY, Assistant Entomologist

Investigations of Insects Affecting the Health of Man and Animals
Bureau of Entomology

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The use of airplanes for distributing arsenical dusts in the control of insect pests affecting cotton has been the subject of experiment during the last three years by the Delta Laboratory of the Bureau of Entomology, United States Department of Agriculture, in cooperation with the United States Army Air Service. The headquarters for this work was at Tallulah, La., a short distance from the bureau's station for malaria mosquito investigations at Mound, La., so that, with the offer of cooperation from the Delta Laboratory and the Air Service detachment engaged in cotton-dusting experiments, an excellent opportunity was presented for testing the possibilities of employing airplanes[1] in the control of the breeding of Anopheles mosquitoes in large swamp areas, Paris green being used as the larvicide. It was obvious that if this insecticide should prove satisfactory for the purpose and if its distribution by airplane should prove successful, the extent of the area which could be treated would be many times greater than that which could be covered by any other treatment now in use.

[1] The writers are greatly indebted to B. R. Coad, of the Bureau of Entomology; Elmer Johnson, of the Bureau of Public Roads; and Lieut. G. L. McNeil and Sergeants McConnell and McGinley, of the United States Army Air Service, for their cooperation and assistance in the dusting experiments.

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Considering the extent of the swamp areas in the region, the small proportion of cultivated land, and the limited population, it did not appear altogether likely that such a method would prove to be a practical means of malaria control under these particular conditions. Such swamp areas prior to drainage are, however, almost inaccessible to any other means of treatment, and it seemed entirely possible that airplanes might be of practical use under similar or other conditions where the per capita cost of the operations would not be excessive.

In the cotton-dusting work it has been found that, under favorable conditions, several hundred acres an hour can be treated by a single plane and that the dust can be thoroughly distributed over the fields. The swamp areas, however, present much more difficult flying conditions than the open cotton fields, and the principal preliminary questions to be decided were (1) whether the planes could be safely flown over such areas and (2) whether the dust could be released so as to reach the water surface in effective quantities. One factor which appeared to favor the distribution of dust in such a manner was that the direction of the air currents is usually downward over woods and bodies of water, whereas over open ground it is upward.

The experiments were carried out during 1923 and 1924, Army DeHaviland 4–B planes, operated by Air Service pilots, being used. A light metal hopper designed to hold 300 pounds of calcium arsenate was built into the rear cockpit, and the dust was released through an opening provided in the bottom of the fuselage.[2]

THE INSECTICIDAL DUST USED

Paris green appears to be the most promising larvicide available for airplane dusting in control of Anopheles larvæ, and it was the arsenical used in all the experiments. It has proved to be as effective as oil in control of Anopheles larvæ,[3] is very much less costly than oil, and can be applied in dry form suitable for distribution by airplane. Unfortunately it is not satisfactory as a general larvicide, since it does not destroy the larvæ of other mosquitoes which do not have the surface-feeding habits of Anopheles, and it remains effective on the water for only a very short time. On the other hand, in the quantities used, it is not poisonous to the insects and small fishes which prey upon mosquito larvæ.

Since only a very small quantity of Paris green is necessary to kill mosquito larvæ, an inert dust of some sort was used as a diluent and carrier. For the airplane mixtures a finely ground silica earth was the diluent principally used. A "double-ground" product was uniform in quality and was found to have about the same density as Paris green, a factor thought to be of possible importance because of the strong air blast to which the mixtures are subjected when released from the hoppers and which would tend to separate substances of different weights and composition. A much finer "air-float" product from the same source was also tried, as well as foundry

[2] A description of earlier experiments with airplanes is given in U. S. Dept. Agr. Bul. 1204, Dusting Cotton from Airplanes, by B. R. Coad, E. Johnson, and G. L. McNeil.

[3] M. A. Barber and T. B. Hayne. Arsenic as a larvicide for anopheline larvæ. *In* U. S. Pub. Health Serv., Pub. Health Rpt., vol. 36, pp. 3027–3034. 1921.

"parting," but the former was found to be too light in weight and likely to drift away without settling. The "parting" contains 2 per cent of oils and is relatively waterproof, but unfortunately it did not improve the floating qualities of the Paris green.

Other carriers used were ordinary road dust and a mixture of lime and flour. In the few tests in which these were employed, no evidence was obtained of a separation of the carrier and the arsenical; but the tendency of the flour and lime to become packed in the hopper, owing to the vibration of the plane, was a drawback to its use. Although road dust is a satisfactory carrier for hand applications, it seemed desirable to obtain a substance more uniform in quality and more certain as to source of supply for any airplane work on a large scale.

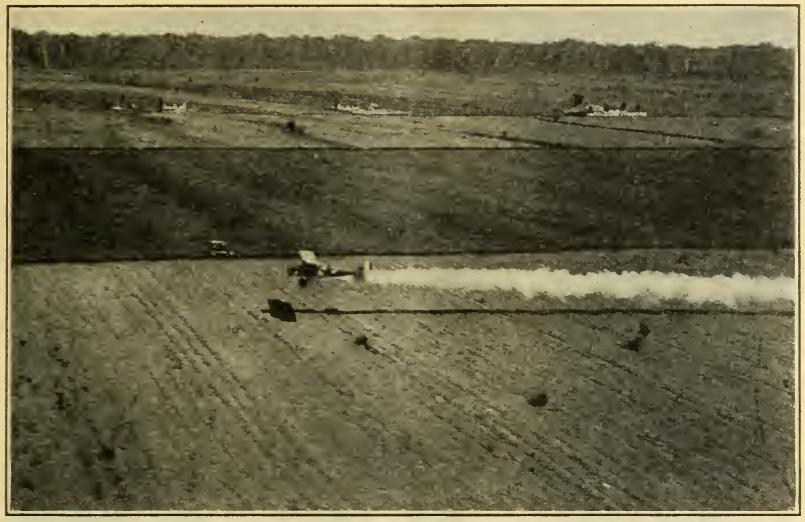

FIG. 1.—Dusting plane flown across open field to determine the spread of the Paris green and dust mixture under the most favorable conditions. Plane flying about 15 feet above the ground

PRELIMINARY EXPERIMENTS TO DETERMINE DISTRIBUTION OF THE DUST ON THE GROUND AND MINIMUM KILLING DOSAGE

In preliminary ground experiments the approximate minimum concentration of Paris green necessary to kill the larvæ was determined by placing side by side a series of dry glass plates 2 by 3 inches in size and open dishes containing water and Anopheles larvæ and dusting the two with varying quantities of Paris green with a hand duster. The larvæ were then watched for 24 hours to determine their mortality, and the numbers of granules of the Paris green per square inch were counted on the glass plates with a low-power microscope.

Following this the first airplane tests were made over open ground, glass plates being used as a means of determining the drift of the dust and the quantity which settled to the ground. In these tests, in which various mixtures were used, the plane was flown from 15 to 30 feet above the ground (fig. 1) and at right angles to the direc-

tion of the wind and to two lines of glass plates placed at intervals across an open field. In the best of the trials it was found that a strip from 300 to 400 feet wide had been effectively treated by one trip of the plane and that the quantity of Paris green required was at the rate of about 1 pound to 20 acres. This represented the minimum quantity effective on water containing almost no débris or aquatic growth. Under such conditions the writers' counts had shown that 10 or more granules of Paris green per square inch usually gave 100 per cent mortality, whereas with a lower count some of the larvæ escaped. In these preliminary tests and in the next series also a count of 10 granules per square inch was therefore taken as the effective dosage, although it was found later that this quantity was insufficient under natural breeding conditions where the larvæ

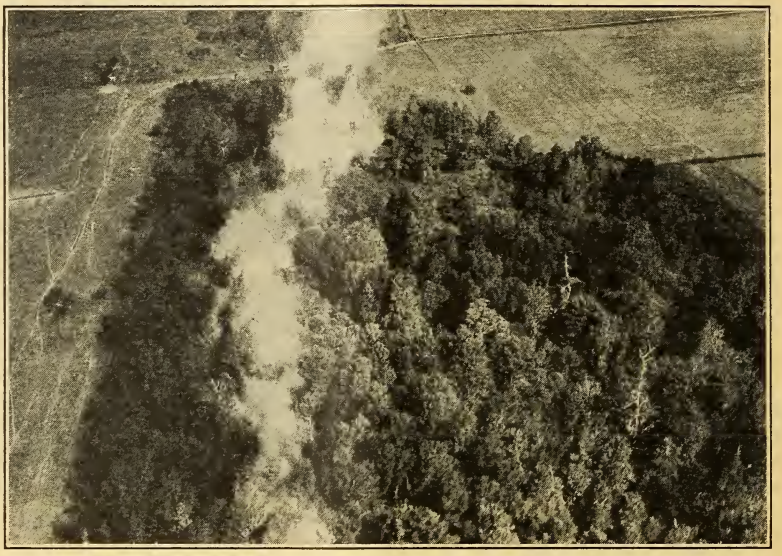

FIG. 2.—Dust cloud beginning to spread out among the trees following a trip of the plane across Bunkum Woods

are more protected by the débris and vegetation among which they feed.

The next tests were made in two patches of woods, to determine whether the dust could be forced to the ground through a growth of leaves and brush. In the first of these the strip of woods was fairly narrow, with only a moderately heavy growth of timber. Two parallel lines of glass plates were placed on the ground under the trees and the plane was flown at right angles to these lines, making two or three trips across the woods at about the same place each time (fig. 2). The mixture distributed consisted usually of 100 pounds of dust containing 10 pounds of Paris green. The lines of glass plates, with 10 in each, were distributed across a strip 750 feet wide. In the best one of the trials all of the plates showed the presence of Paris green, and all except two in one line had 10 or more granules per square inch.

In the second patch of woods the conditions for dusting were extremely difficult, as the timber was very tall and the growth was so dense that the ground was almost completely shaded. Two lines of glass plates were placed on the ground as before, except that they were spaced at 100-foot instead of 75-foot intervals. Three tests were made with the dusting plane, in none of which was there failure to find Paris green on some of the plates. In one case 8 of the glass plates in one line and 7 in the other were dusted. For the three flights, the average width of the strip which received 5 or more granules per square inch was about 300 feet, and the average width of that receiving 10 or more grains per square inch was about 200 feet. It was thus shown that, even in dense woods, it is possible to reach the ground through the cover of vegetation, although much of the material is lost because it adheres to the leaves or drifts away with the wind.

In Table 1 is given a summary of the dusting operations over the wooded areas.

TABLE 1.—*Airplane dusting over dry woods to determine distribution of the poison on the ground underneath, Mound, La., 1923*

BUNKUM WOODS

Date	Mixture	Number of trips across	Number of glass plates dusted (2 lines of 10 each)	Width of strip	Number of glass plates with 10 or more grains of Paris green per square inch	Width of strip
1923				*Feet*		*Feet*
July 12	[1] 5-100	2	6	450	0	0
			7	525	0	0
13	10-100	2	6	450	2	150
			6	450	0	0
17	10-100	3	7	525	4	300
			9	675	6	450
18	10-100	3	10	750	10	750
			10	750	8	600

ASHLEY WOODS

				Feet		*Feet*
July 13	13-130	3	3	300	2	200
			3	300	2	200
17	10-100	2	8	800	2	200
			7	700	0	0
18	10-100	3	4	400	2	200
			5	500	3	300

[1] Five pounds of Paris green in 100 pounds of dust.

DUSTING MOSQUITO-BREEDING LAKES

Following these trials the dusting of mosquito-breeding lakes was undertaken, and three locations were selected as offering suitable conditions for the tests. These conditions were an abundance of larvæ in the water and proximity of the areas to open fields. The latter was of importance as a possible measure of safety in the event of a forced landing. It was desirable, moreover, that the lakes should be as accessible as possible from solid ground, because much

work is required in making preliminary examinations and in checking the results.

A full description of the shallow swamp lakes found in this region has been published recently by one of the writers[4] and will not be repeated in detail here. In general, they are the principal sources of Anopheles mosquitoes and as a rule consist of a central treeless area of more or less permanent water, surrounded by a dense marginal growth of trees and brush. (Fig. 3.) The central area is usually overgrown with water chinquapin and water lilies (Nelumbo and Castalia) and other smaller aquatic vegetation. In winter the lakes become filled and the water spreads out into the woods, often covering large areas and producing favorable conditions for mosquito breeding in spring and early summer. As the excess water drains away or evaporates, the larvæ are found in the more open

FIG. 3.—One of the larger swamp lakes

parts of the lakes away from the trees. The principal difficulty anticipated in treating such areas was in reaching the larvæ in the wooded marginal zones.

In the first of the three lakes selected, known as Field Lake, the open part was something over a half mile in length and perhaps one-fourth as wide as long. Between the lake and a cleared pasture on one side was a narrow fringe of flooded woods varying in width from 50 to 200 feet. Breeding was prolific in this fringe and in places in the open lake, under the thick growth of lilies and in mats of mud plantain and Ceratophyllum. In preparing for the dusting flights larval examinations were made at 10 or more points in the part of the lake to be treated, and a glass plate was left on a floating block at each of these "stations." From the plates it was possible to

[4] G. H. Bradley. The natural breeding places of Anopheles mosquitoes in the vicinity of Mound, La. *In* Amer. Jour. Trop Med., vol. 4, pp. 199–223, 1924.

determine the concentration of Paris green which had reached the water, and on the morning following the dusting a corroborative examination for larvæ was made. The stations were usually located in the parts of the area most difficult for treating—that is, at the ends and in the brush at the margins.

Of the six applications given this lake the highest average mortality for one set of 10 stations was 93.5 per cent. A set of stations in another portion of the lake, treated in the same operation, showed a mortality of 87.5 per cent. In one other trial 93 per cent was killed, but the remaining applications were variable in results and in one instance a complete failure.

The treatment of the open part of the lake was largely a matter of skillful flying and estimation of the wind drift. (Fig. 4.) In the operation the planes were brought down in a dive to below the line

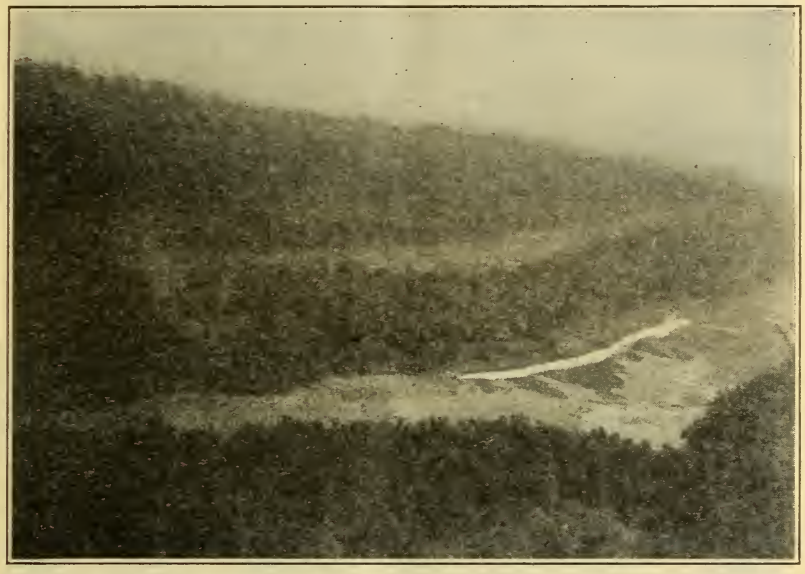

FIG. 4.—Dusting plane making a flight over the center of Ex Via Lake, flying below the tops of the trees on each side

of surrounding trees, then leveled out across the lake, and "zoomed" over the timber at the other end, the upward direction of the plane in "zooming" serving to blow the dust with great force down into the pockets and thick brush at the ends.

At the time at which the flights were made, usually between 8 and 11 a. m., there was always more or less of a breeze, and the effect on the drift of the dust cloud had to be rather carefully estimated to make the applications effective. This was especially important in treating the wooded areas, since the dust, when released at the height of the tree tops, is easily carried away by the wind. Dusting was usually discontinued when the wind velocity exceeded from 10 to 15 miles per hour. On the other hand, when the dust is released at the right place, a slight wind drift is of advantage in distributing it uniformly, and especially in carrying it into the woods at the margins. (Figs. 5 and 6.)

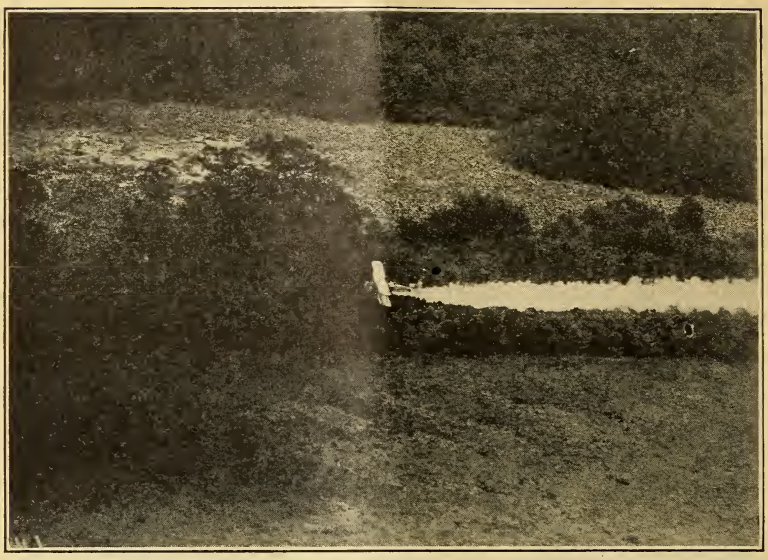

FIG. 5.—Dusting the marginal zone of Field Lake. With the wind blowing toward the lake, the plane was flown outside of the tree line and the dust drifted into the breeding area

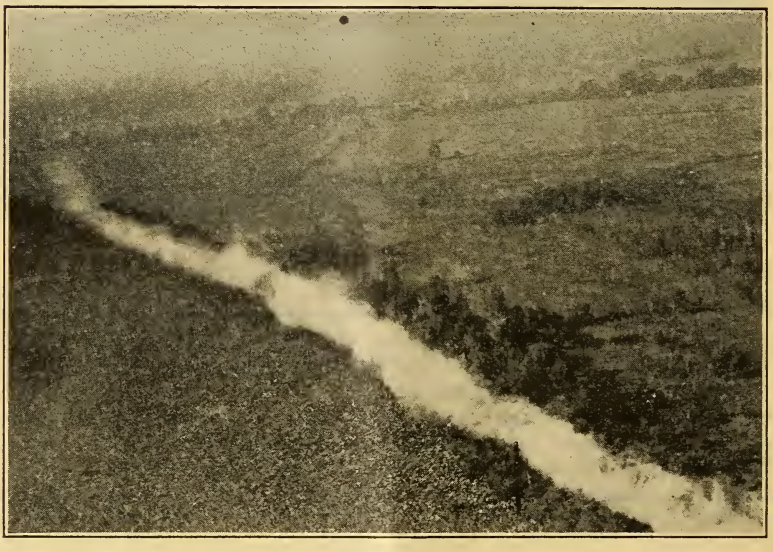

FIG. 6.—View of another dust cloud left in treating the marginal zone of Field Lake. In this case the plane was flown on the lake side of the trees, since the drift was toward the open field. The photograph also shows the heavy growth of water chinquapin, in a portion of the lake completely obscuring the water surface

In the cotton-dusting work the best time for making the applications was found to be immediately after daylight when the air is usually still and the plants covered with dew. In the lake dusting, however, the presence of dew was a decided disadvantage, since it caught and held the dust particles, and this more than offset the advantage of flying early in the morning to avoid the more irregular air conditions encountered later.

The general results of the lake-dusting experiments in 1923 are summarized in Table 2.

TABLE 2.—*Results of lake-dusting experiments*[1] *for destruction of larvæ of malaria mosquitoes, Mound, La., 1923*

Date	Number of stations	Average number of larvae per 10 dips	Average number of poison granules per square inch	Number of stations with 50 per cent or higher mortality	Reduction for entire area
FIELD LAKE					
1923					*Per cent*
Aug. 13	10	35.0	16		67.7
15	10	9.7	27		93.0
22	10	10.7		3	34.6
	8	13.0		1	0
29	10	20.0	133	10	93.5
	10	9.6	163	9	87.5
Sept. 12	10	14.7	24	4	15.6
	10	14.4	38	7	54.9
20	10	20.0	84	9	84.0
	10	18.0		8	88.4
ALGODON LAKE					
Sept. 5	10	20.5	4	2	0.1
10	6	14.3	33	3	14.4
21	6	21.3	120	3	18.8
26	6	22.7	99	4	47.1
TEXAS FIELD LAKE					
Sept. 14	10	15.7	39	2	1.9
25	13	34.8	122	7	47.1
WALNUT BAYOU					
Sept. 28	10	11.4	156	9	78.1

[1] The mixtures used contained from 10 to 50 per cent of Paris green.

On Algodon Lake, the second area selected, conditions for dusting were very difficult, in that the breeding area consisted of a long, narrow strip of water in the midst of a particularly heavy growth of tall willows and buttonbush trees, and without any open space to serve as a guide mark for the pilots. The débris and aquatic growth on the water itself were also unusually thick, and an extra quantity of poison was required for effective results. In none of the four trials at this place were the applications particularly successful, but in three of the four the average quantity of arsenic found on the plates would ordinarily have been considered sufficient. This also

occurred in the two tests on Texas Field Lake, which was the third lake in the series, and consisted of a central open area with a fairly wide overflow out into the woods. The most abundant breeding was found in the overflow water, and the dusting observations were confined to this part of the area.

In nearly all of the lake-dusting experiments one or more places in the lake failed to receive more than a very small quantity of poison; and, on one occasion, the lake under treatment was almost completely missed because the dust drifted away before settling. When the results of the various experiments were analyzed, however, it became apparent that in a number of cases a large quantity of the Paris green had settled upon the water surface without destroying the larvæ. The uniform coating of dust on the glass plates indicated that the distribution had been thorough; and, on one or two occasions, it was observed by the examiners that living Anopheles larvæ and green arsenic pellets floating on the water were to be picked up in the same dip. This was contrary to the writers' experience with hand distribution, and suggested some connection with the method of application.

For various reasons it was not possible to conduct a large series of tests in 1924; but, from the few which were made, it was indicated that the difficulty in 1923 had been due to some defect in the Paris green itself. Two lots had been used that year, and the trouble had arisen with the second one, although it has not as yet been determined wherein this differed from other samples. A new stock was obtained for 1924; and, although an excessive quantity was put in the mixtures because of the previous experience, a number of stations gave a high larval mortality where only a small quantity of the arsenical was found to have reached the water.

Owing to the long drought in 1924 the woods became almost completely dry, and mosquito breeding was limited to the water remaining in the more open parts of the swamp lakes. The experiments could not therefore be repeated in timber, as had been desired; but, in the two lakes where applications were made (fig. 7), the growth of water chinquapins was extremely dense; and the water surface was a mat of floating and partially submerged vegetation, so that the conditions for the tests were sufficiently difficult.

DUSTING A FLOODED RICE FIELD

Another test of special interest was made in a rice field. The plat selected for this was a 7½-acre cut, with the rice about 20 inches high, and the field flooded with from 4 to 6 inches of water. Anopheles breeding was well distributed throughout. The dusting plane was flown from Tallulah, a distance of about 25 miles, and was landed in a near-by pasture to take on the dust load, which for this test consisted of 5 pounds of Paris green in 100 pounds of Tripoli earth. The actual time required for dusting the field was a matter of only a few minutes.

During the flight the wind was rather strong, and as a result one edge of the field was missed on account of the failure of the plane to go far enough upwind to offset the effect of the drift. Except for this, the distribution was rather thorough and the quantity of dust

used was considerably more than enough to cover the field. For the whole cut an estimated mortality of 73 per cent resulted, but with the exception of the one edge practically 100 per cent of the large larvæ were destroyed as well as the majority of the small ones. In this connection it may be noted that when mortality of the larvæ is not complete those from one-half to full grown are always the first to succumb.

The level nature of the rice fields made very favorable conditions for airplane dusting, and the only difficulties in the way of effective treatment appeared to be in the case of fields adjoining the woods or where the hedgerows along the ditch banks were high. Some of the

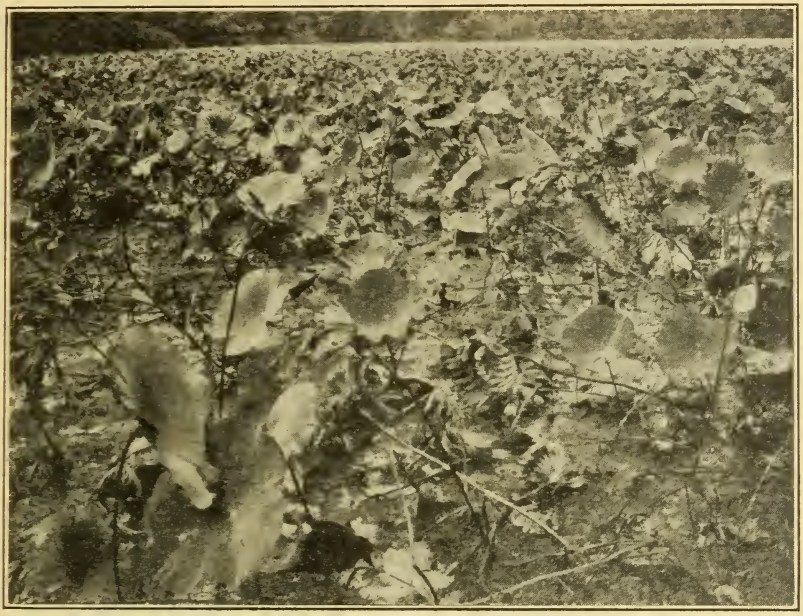

FIG. 7.—Growth of water chinquapin in Blue Front Lake at the time of the dusting test in 1924

dust was wasted because it remained on the leaves, but when these were dry the mixture did not adhere to them to any great extent. It was found from other experiments that the leaves of the rice plants are very susceptible to burning when a large quantity of Paris green is used, but the quantity necessary to kill Anopheles larvæ did not prove destructive to the plants, and in a few small plat tests, where excessive quantities were applied, even severe burning of the leaves did not appear to kill the plants or to prevent normal development of the grain.

The summaries of the dusting operations in 1924 are given in Tables 3 and 4, which include the records for the individual stations.

TABLE 3.—*Airplane dusting*[1] *on rice field for destruction of Anopheles larvæ, Mound, La., 1924*

Station No.	Part of field	Number of larvæ in 10 dips	Number of Paris green granules per square inch	Reduction following dusting
				Per cent
1	East	9	347	100
2	do	30	236	100
3	do	36	84	72
4	do	22	42	73
5	do	26	74	77
6	do	8	48	25
7	do	4	66	50
8	do	8	54	0
11	Center	16	68	100
12	do	10	86	90
13	do	15	8	80
14	do	18	2	44
15	do	8	2	12
16	West	32	45	100
17	do	18	48	100
18	do	11	73	82
19	do	25	20	80
20	do	7	2	0
	Average	16.8	72	73.0
Average, exclusive of stations Nos. 14, 15, and 20				78.5
Per cent reduction of larvæ over half grown, exclusive of stations Nos. 14, 15, and 20				99.0

[1] Five pounds of Paris green and 100 pounds of dust were used.

TABLE 4.—*Lake dusting for destruction of Anopheles larvæ; Mound, La., 1924*

EX VIA LAKE

Dosage: 20 pounds of Paris green to 140 pounds of Tripoli earth

Station No.	Number of larvæ in 10 dips	Number of Paris green granules per square inch	Reduction from dusting	Killed in pans containing 10 larvæ each
			Per cent	*Per cent*
1	80	6	55	50
2	36	151	94	100
3	44	22	93	80
4	24	38	100	100
5, 6	10	232	100	100
7	16	139	100	100
8, 9, 10	43	82	96	(1)
11	45	276	100	100
12	8	193	100	100
13	4	146	100	(1)
14	20	214	100	100
15	46	150	100	(1)
16	14	124	71	(1)
17	14	245	86	(1)
Average	23.9	144	88.0	91.8

[1] No pan.

BLUE FRONT LAKE

Dosage: 30 pounds of Paris green to 120 pounds of Tripoli earth

1	20	390	100	100
2	18	662	100	100
3	17	838	100	100
4	16	810	100	100
5	24	420	100	100
6	14	499	100	100
7	13	524	100	100
8	25	172	100	100
9	14	419	100	100
10	17	33	91	100
11	15	43	100	100
Average	17.5	437	99.1	100

AN ADDITIONAL CHECK ON THE RESULTS

As an additional check on the results of the poisoning in the two completed experiments porcelain pans 11 inches in diameter and containing 10 larvæ each were placed at the different stations before the dust was applied and were examined the following day for the percentage killed. (Fig. 8.) On Ex Via Lake all the larvæ were dead in seven out of nine pans, whereas, in the other two pans, 5 larvæ remained alive in one and 2 in the other. The first of these was in a pocket along the shore, and this was the only part of the area where any considerable number of larvæ were found remaining after the treatment. A few small larvæ were found at several of the

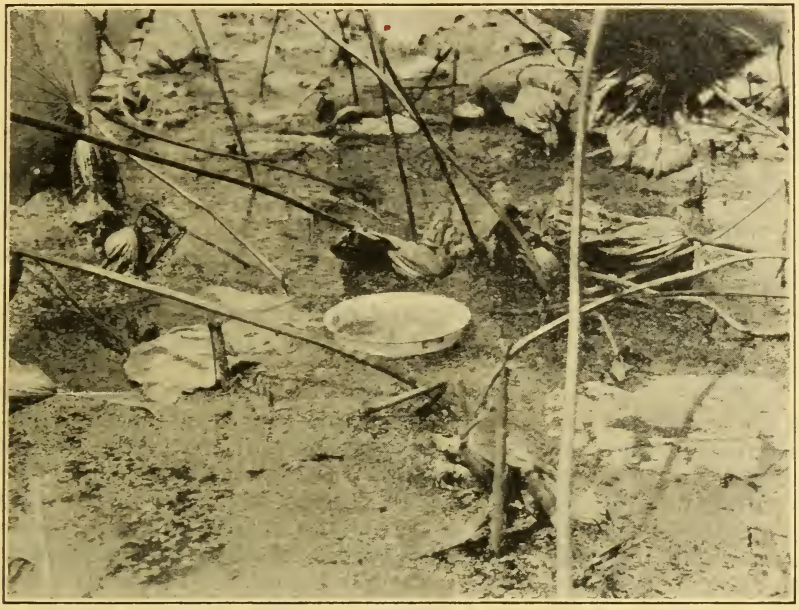

FIG. 8.—One of the pans containing larvae and floating on the surface of the water as used in the lake-dusting experiments in 1924. The view also shows the water conditions encountered during these tests

other stations and the total reduction for the whole area was 88 per cent.

At the second lake the treatment was highly successful, as all of the larvæ in the 11 pans were killed and none were to be found in the lake water in any part of the area except at one place where a small quantity of dust had fallen and where a few of the very smallest larvæ had escaped. The number found remaining was less than 1 per cent of the total counted in the examinations made previous to dusting.

SUMMARY

Dusting Paris green from airplanes to control the breeding of Anopheles mosquitoes was tried in 1923 and 1924 on the extensive swamp and marsh areas in the vicinity of Mound, La. Army model DeHaviland planes were employed and were operated by United

States Army Air Service pilots. These planes had been adapted for cotton dusting by installing metal dust hoppers in the rear cockpits with an arrangement provided for releasing the dust through the bottom of the fuselage.

In developing the method of handling the planes so as to distribute the dust properly and in determining the quantity of Paris green to use, flights were made first over open fields, then over dry woods, and finally over various types of mosquito-breeding swamp and lake areas. As the Paris green is effective in very small quantities, it was diluted by mixing it with an inert carrier before it was distributed. For this purpose a fine silicious earth was used in most of the tests, although ordinary road dust and a mixture of flour and lime were employed on a few occasions with fairly good results.

From these tests it was found that a given area could be covered rather thoroughly with the dust, and that by taking advantage of a light breeze a wide strip could be treated with each trip of the plane. A wind velocity as high as 10 to 15 miles per hour was, however, a disadvantage in making the dust applications, and the operations were usually discontinued when the stronger winds were blowing.

In addition to the different types of marsh and lake areas treated in the two seasons, applications were made on a section of one of the natural bayous and on a small field of rice. The results of the entire series of tests in the reduction of larvæ were variable, owing in part to the failure of the dust to reach all of the area under observation and in part to an unsatisfactory lot of Paris green which was used in a number of the experiments and which proved to have a very low toxicity for the larvæ.

With an experienced pilot, and when careful attention was given to the spread of the dust, no special difficulty was encountered in distributing the dust over the treeless part of the lakes. Furthermore, from the single experience in treating rice fields, this type of breeding place appears to be particularly well adapted to control by airplane dusting, because of the absence of trees and other obstructions which interfere with close flying. As had been anticipated, the most difficult conditions encountered were in the heavily wooded areas where the water was protected by dense overhead foliage, and where the planes had to be flown high enough from the ground to clear the tallest trees. Even in such places, however, the dust was found to have penetrated the thick growth and to have reached the water in sufficient quantities to destroy the larvæ when enough of the dust had been used to offset the increased wastage. Under such conditions the loss of dust due to adherence to the leaves and to wind drift was considerable.

The quantity of Paris green used in the experiments varied from about one-twentieth of a pound to several pounds per acre. Exclusive of the tests in which the poor sample of Paris green was used, the writers' experience indicates that approximately one-half pound per acre will give a safe margin for the treatment of such places as rice fields and the more open parts of the lakes, the quantity being increased as necessary where the breeding area is protected by a growth of trees and brush.

The two final tests of 1924 gave particularly clear-cut results, and for this reason were of special interest in showing the possibilities

of this method of control in breeding areas of the type represented, the lakes being overgrown with aquatic vegetation and having an abundance of Anopheles larvæ well distributed throughout. In the first of these a larval reduction of 88 per cent occurred as a result of the treatment, and in the second over 99 per cent were killed, as estimated by the writers' method of examination. The only larvæ remaining in the second instance were a few of the smallest size, which were found in one small spot. In each test a series of pans containing a counted number of larvæ were distributed over the lake as a further check on the effectiveness of the poisoning. In the first test 92 per cent of these larvæ were killed and in the second all were destroyed.

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